AFRL-RH-WP-TR-2013-0116

ASSESSMENT OF REFUELING HOSE VISIBILITY: POST-CLEANING EVALUATION

Sharon A. Ellis
Alan R. Pinkus, Ph.D.
Warfighter Interface Division

H. Lee Task, Ph.D.
Task Consulting

October 2013

AIR FORCE RESEARCH LABORATORY
711 HUMAN PERFORMANCE WING,
HUMAN EFFECTIVENESS DIRECTORATE,
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

NOTICE AND SIGNATURE PAGE

AFRL-RH-WP-TR-2013-0116 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//signed//
Sharon A. Ellis
Work Unit Manager
Battlespace Visualization Branch

//signed//
JEFFREY L. CRAIG, Chief
Battlespace Visualization Branch
Warfighter Interface Division

//signed//
WILLIAM E. RUSSELL, Acting Chief
Warfighter Interface Division
Human Effectiveness Directorate
711th Human Performance Wing

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* 28-10-2013	**2. REPORT TYPE** OTHER	**3. DATES COVERED *(From - To)*** 2 Sep 2013 – 2 Oct 2013
4. TITLE AND SUBTITLE ASSESSMENT OF REFUELING HOSE VISIBILITY: POST CLEANING EVALUATION		**5a. CONTRACT NUMBER** IN-HOUSE
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER 62202F
6. AUTHOR(S) Sharon A. Ellis*; Alan R. Pinkus, Ph.D.* H. Lee Task, Ph.D.**		**5d. PROJECT NUMBER** 7184
		5e. TASK NUMBER 11
		5f. WORK UNIT NUMBER H03F (71841143)
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Task Consulting** 2466 W. Golden Hill Rd. Tucson AZ 85745-1879		**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Materiel Command* Air Force Research Laboratory 711th Human Performance Wing Human Effectiveness Directorate Warfighter Interface Division Battlespace Visualization Branch Wright-Patterson AFB OH 45433-7022		**10. SPONSOR/MONITOR'S ACRONYM(S)** 711HPW/RHCV
		11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-RH-WP-TR-2013-0116

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A: Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
88 ABW Cleared 12/17/2013; 88ABW-2013-5361. Report contains color.

14. ABSTRACT This technical report is a supplemental follow-on evaluation to the effort "Assessment of Refueling Hose Visibility" (AFRL-RH-WP-TR-2012-0145). In the original report, there was considerable information on the theoretical basis behind determining hose visibility and specific measurement procedures and geometries were described and implemented (see Appendices B and C). The purpose of this report is to accomplish many of the same visibility measurements on the same hose samples after they were cleaned. This report compares the measured visibility parameters before and after cleaning.

15. SUBJECT TERMS
Aerial refueling hose, visibility, contrast, illumination, viewing geometries, spectral band, NVG, SWIR, LWIR, standards

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Sharon A. Ellis
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	SAR	37	**19b. TELEPHONE NUMBER** *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

ACKNOWLEDGEMENTS

This study was proposed by the Aerial Refueling Systems Advisory Group (ARSAG) Workshops / DOD Joint Standardization Board (JSB) for Aerial Refueling Systems. Technical cooperation was afforded by ARSAG / JSB through the JSB Chair, Tom Cavallaro, NAVAIR; Working Group Lead, Stephanie Mousseau, NAVAIR; JSB Deputy Chair, Mark Burket, AFLCMC/EZFA; and Dexter Kalt, ARSAG Executive Director. Sponsorship of this study was provided by the OSD Defense Standardization Program Office, through the cooperation of Lloyd Thomas. The assistance of military and industry organizations, NAVAIR, Eaton Aerospace and Omega Air, in providing aerial refueling hose samples is appreciated.

The authors gratefully acknowledge the excellent technical support of David Sivert (Ball Aerospace & Technologies Corp.) who photographed the samples, setup the photometric tests, and collected all the data needed for the report analyses. We also thank James Garrett (Consortium Research Fellow) for his assistance in the preparation of the final report.

Table of Contents

List of Figures

List of Tables

1 SUMMARY

This technical report is a supplemental follow-on evaluation to the effort "Assessment of Refueling Hose Visibility" (AFRL-RH-WP-TR-2012-0145). In the original report, there was considerable information on the theoretical basis behind determining hose visibility and specific measurement procedures and geometries were described and implemented (see Appendices B and C). The purpose of this report is to accomplish many of the same visibility measurements on the same hose samples after they were cleaned. This report compares the measured visibility parameters before and after cleaning.

2 INTRODUCTION

The primary guiding statement for the original refueling hose visibility evaluation for the earlier report referenced above (and for this report) stems from section 3.1 of Appendix A (Aerial Refueling Hose Color and Markings Evaluation Criteria):

> *Acceptable minimum / maximum hose color to marking contrast range under a variety of lighting conditions. This should permit the pilots to detect hose movement and position from the tanker hose / drogue exit. This distance (pilot eye to drogue exit) may range from approximately 10‘ to 90‘ depending on the type of tanker drogue hose reel retracting / storage system.*

This statement makes it clear that the primary objective of this effort is to determine how well a pilot can see the markings on the refueling hose in order for the pilot to make judgments of hose movement and position. As suggested in the excerpt above, one of the key factors in determining the visibility of hose markings is the contrast between the hose markings and the rest of the hose under various lighting conditions. Note that this visibility objective is different than determining the visibility of the hose (marked or unmarked sections) against a variety of background scenes.

The original report provides a fairly extensive discussion of contrast and contrast ratio as a primary variable affecting the visibility of an object. Since that material is not repeated here, the interested reader is encouraged to obtain the original (corrected) technical report (AFRL-RH-WP-TR-2012-0145). After completion of the original hose visibility study, the Aerial Refueling Systems Advisory Group (ARSAG) requested that there be a follow-on effort to evaluate the same hose samples after cleaning to see what effect the cleaning process had on visibility. The six samples were sent back to ARSAG to be cleaned by personnel experienced in cleaning refueling hoses and then sent back to AFRL for re-evaluation. This report contains both the results of the re-evaluation as well as the original evaluation results to allow for easy comparison of the effect of cleaning these hose samples.

Figure 1 contains six sets of "before" and "after" pictures of the hose samples. In each pair of numbered pictures, the number refers to the hose sample number as used in the first study. The upper picture of each pair is a picture of the hose sample after cleaning and the lower picture is the hose sample before cleaning. Some effects of the hose cleaning are fairly obvious for these visible spectrum photographs, such as the extreme improvement in the appearance of the "white" part of hose sample number 6 after cleaning; or the removal of the white scuff marks in the black area of hose sample number 4. Table 1 provides a description (provided by ARSAG) for each of the six hose samples assessed in this effort.

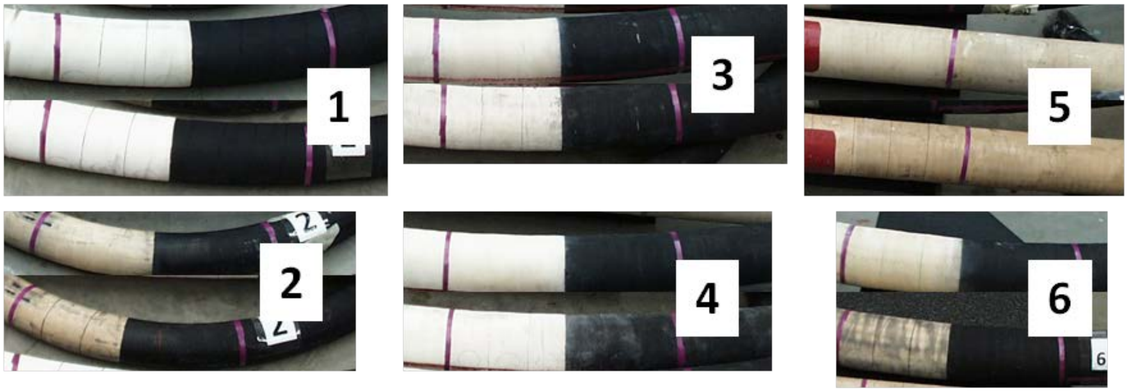

Figure 1. Hose samples - *after* cleaning (top image of each sample and *before* cleaning (bottom image).

Table 1. The six hose samples.

Hose #	Descriptor
1	New Eaton hose, black and white, equal distance of both sample sections, measured black and white. 2.5" outside diameter
2	Used Buddy-Store, black hose with 1 foot wide white markings, measured black and white. 2.0" outside diameter
3	Used Omega (KC-707), white hose with 1 foot black markings, measured black and white. 2.88" outside diameter
4	Used Omega (KC-707), white hose with 1 foot wide black markings (white powder smeared onto black markings) Measured black and white (SN0632 Durodyne 841023AA1116). 2.90" outside diameter
5	Used (original) Omega (KC-707) white hose, no markings reference only 2005 test sample USAF/UDRI report test results, approximately 12 year old sample stored in garage for 9 years. Condition tan/off white appearance, measured two spots (may be original KC-707 Omega hose). 2.75" outside diameter
6	Used KC-130, black hose with 1 foot white markings. Actual use and age is unknown. Provided by NAVAIR/Pax River test agency. Condition, white markings deteriorated, scuffed in some cases, black (base) hose showing in several spots under white markings. Measured black-white 1 foot marking. 2.83" outside diameter

3 MEASUREMENT OF HOSE SAMPLES AFTER CLEANING

3.1 Photometric Reflectance: Non-specular Illumination Geometries

The reflectance coefficients of each of the six hose samples were measured for several viewing/illumination geometries. This section deals with the reflection coefficients (from which the hose marking contrast ratios are calculated) that were measured using non-specular reflection geometries. Two non-reflecting geometries were used: viewing (measuring) perpendicular to the surface of the hose with illumination provided by light sources on either side of the viewing location (Figure 2) and viewing the hose from different view angles with the illumination provided from a single light source perpendicular to the hose (Figure 3).

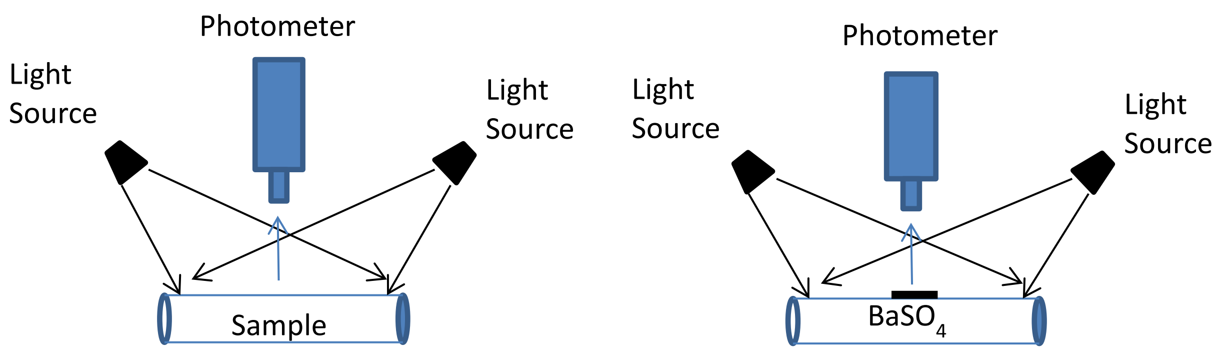

Figure 2. Measurement perpendicular to the surface illumination at 45 degrees on either side.

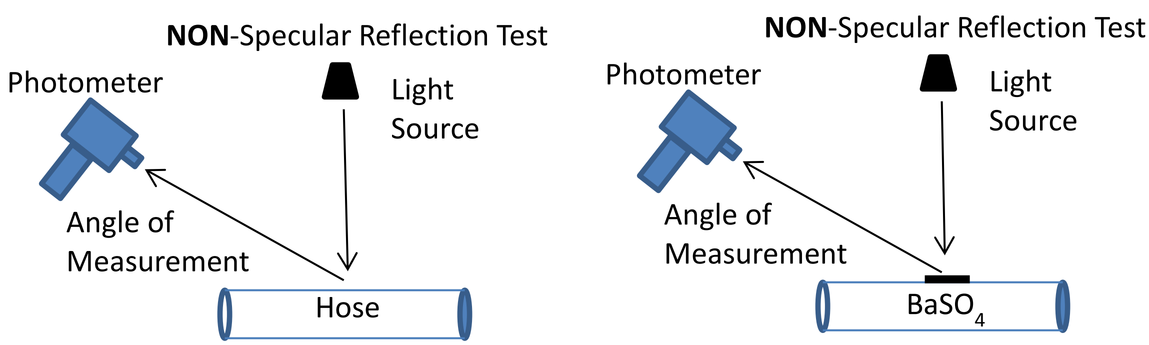

Figure 3. Illumination perpendicular to the surface viewing (measurement) at different angles.

In the case of Figure 2, the hose was measured in three different areas on either side of, and close to, the demarcation between the light and dark part of the hose, as shown in Figure 4. This provided a sample of reflectance coefficients (for this geometry) for each of the hoses.

Figure 4. The measurement locations for "data takes" A, B, and C.

Measurements collected **BEFORE CLEANING** for the non-specular reflectance geometry of Figure 2 are summarized in Table 2 below **(extracted from AFRL-RH-WP-TR-2012-0145)**:

Table 2. <u>BEFORE CLEANING</u>: non-specular reflectance data with photometer aimed perpendicular to the surface and illumination sources provided on either side of the photometer (Figure 2).

Data take			Hose Number 1	2	3	4	5	6
Data Take A	Black Luminance		2.345	2.314	2.799	4.479		2.184
	BaSO4 Luminance		65.03	65.18	66.52	65.7		64.84
	Black Reflectance		0.036	0.036	0.042	0.068		0.034
	White Luminance		41.91	17.61	43.89	44.72	23.34	18.79
	BaSO4 Luminance		64.99	65.08	66.53	65.62	65.56	64.83
	White Reflectance		0.645	0.271	0.660	0.681	0.356	0.290
	Contrast Ratio		**17.9**	**7.6**	**15.7**	**10.0**		**8.6**
Data Take B	Black Luminance		2.165	2.647	2.552	3.19		2.28
	BaSO4 Luminance		64.9	65.06	66.59	65.62		64.92
	Black Reflectance		0.033	0.041	0.038	0.049		0.035
	White Luminance		44.43	17.97	39.46	43.36	23.35	20.18
	BaSO4 Luminance		64.99	65.02	66.53	65.5	65.4	64.96
	White Reflectance		0.684	0.276	0.593	0.662	0.357	0.311
	Contrast Ratio		**20.5**	**6.8**	**15.5**	**13.6**		**8.8**
Data Take C	Black Luminance		2.236	3.103	2.714	2.54		2.357
	BaSO4 Luminance		64.94	65.06	66.4	65.37		64.46
	Black Reflectance		0.034	0.048	0.041	0.039		0.037
	White Luminance		45.57	18.95	39.75	44.28	23.7	17.83
	BaSO4 Luminance		64.72	65.12	65.87	65.23	65.67	64.58
	White Reflectance		0.704	0.291	0.603	0.679	0.361	0.276
	Contrast Ratio		**20.4**	**6.1**	**14.8**	**17.5**		**7.6**

The unshaded cells are the raw data. For each "data take" section, the first two shaded rows are the black reflectance coefficients and the white reflectance coefficients, respectively. The last darker shaded row for each "data take" is the calculated contrast ratio for each hose (with the exception of hose #5, which was “all white” with no markings) and that "data take."

Table 3. <u>AFTER CLEANING</u>: non-specular reflectance data with photometer aimed perpendicuar to the surface and illumination sources provided on either side of the photometer (see Figure 2).

Data take		Hose Number					
		1	**2**	**3**	**4**	**5**	**6**
Data Take A	Black Luminance	1.451	1.623	1.59	1.632		1.746
	BaSO4 Luminance	45.64	45.98	45.58	45.33		45.25
	Black Reflectance	0.032	0.035	0.035	0.036		0.039
	White Luminance	26.14	16.94	25.21	21.16	18.21	18.07
	BaSO4 Luminance	45.69	45.78	45.62	45.35	45.37	45.26
	White Reflectance	0.572	0.370	0.553	0.467	0.401	0.399
	Contrast Ratio	**18.0**	**10.5**	**15.8**	**13.0**		**10.3**
Data Take B	Black Luminance	1.334	1.842	1.622	1.625		1.552
	BaSO4 Luminance	45.65	45.68	45.54	45.4		45.26
	Black Reflectance	0.029	0.040	0.036	0.036		0.034
	White Luminance	29.25	21.11	24.49	23.75	18.53	21.11
	BaSO4 Luminance	45.54	45.73	45.45	45.32	45.31	45.3
	White Reflectance	0.642	0.462	0.539	0.524	0.409	0.466
	Contrast Ratio	**22.0**	**11.4**	**15.1**	**14.6**		**13.6**
Data Take C	Black Luminance	1.388	2.05	1.598	1.362		1.65
	BaSO4 Luminance	45.61	45.75	45.38	45.34		45.21
	Black Reflectance	0.030	0.045	0.035	0.030		0.036
	White Luminance	28.43	15.83	24.21	24.78	**17.75**	21.36
	BaSO4 Luminance	45.64	45.73	45.45	45.34	45.27	45.32
	White Reflectance	0.623	0.346	0.533	0.547	0.392	0.471
	Contrast Ratio	**20.5**	**7.7**	**15.1**	**18.2**		**12.9**

The unshaded cells are the raw data. For each "data take" section, the first two shaded rows are the black reflectance coefficients and the white reflectance coefficients, respectively. The last shaded row for each "data take" is the calculated contrast ratio for each hose (with the exception of hose #5, which was “all white” with no markings) and that "data take."

Table 4. <u>BEFORE CLEANING</u>: non-specular reflectance data with the light source aimed perpendicular to the surface and the view (measurement) angle varied from 60 degrees to 30 degrees (see Figure 3).

View angle from Horz			Hose Number 1	2	3	4	5	6
60 degrees	Black Luminance		1.62	2.493	1.792	2.915		1.6
	BaSO4 Luminance		43.56	45.74	43.17	43.65		44.37
	Black Reflectance		0.037	0.055	0.042	0.067		0.036
	White Luminance		28.94	13.82	28.64	27.36	15.73	12.61
	BaSO4 Luminance		44.06	45.97	43.11	43.76	43.2	44.44
	White Reflectance		0.657	0.301	0.664	0.625	0.364	0.284
	Contrast Ratio		**17.7**	**5.5**	**16.0**	**9.4**		**7.9**
45 degrees	Black Luminance		1.521	1.656	1.7	2.707		1.58
	BaSO4 Luminance		43.08	42.14	42.24	42.57		43.08
	Black Reflectance		0.035	0.039	0.040	0.064		0.037
	White Luminance		27.12	11.88	27.57	26.29	14.93	11.47
	BaSO4 Luminance		43.18	42.53	42.23	42.62	42.66	43.39
	White Reflectance		0.628	0.279	0.653	0.617	0.350	0.264
	Contrast Ratio		**17.8**	**7.1**	**16.2**	**9.7**		**7.2**
30 degrees	Black Luminance		1.467	1.622	1.749	2.585		1.562
	BaSO4 Luminance		41.38	40.63	42.76	40.68		41.57
	Black Reflectance		0.035	0.040	0.041	0.064		0.038
	White Luminance		26.06	11.13	27.98	25.38	14.32	10.21
	BaSO4 Luminance		41.4	40.72	42.79	40.65	40.66	41.55
	White Reflectance		0.629	0.273	0.654	0.624	0.352	0.246
	Contrast Ratio		**17.8**	**6.8**	**16.0**	**9.8**		**6.5**

As in the previous table, the raw data are in the unshaded cells and the first two shaded rows for a specific measurement angle are the black and white reflectance coefficients, respectively. The third, darker shaded row for each measurement angle section is the calculated contrast ratio for that hose and for that particular viewing (measurement) angle. Again, hose sample #5 was a white hose with no black markings and therefore, no contrast was calculated for this sample.

Table 5. AFTER CLEANING: non-specular reflectance data with the light source aimed perpendicular to the surface and the view (measurement) angle varied from 60 degrees to 30 degrees (see Figure 3).

Angle from horz		Hose Number					
		1	**2**	**3**	**4**	**5**	**6**
60 degrees	Black Luminance	1.3	2.384	1.472	1.526		1.463
	BaSO4 Luminance	39.25	39.16	39.44	39.65		39.83
	Black Reflectance	0.033	0.061	0.037	0.038		0.037
	White Luminance	23.87	15.28	22.02	18.79	16.77	16.41
	BaSO4 Luminance	39.25	39.28	39.34	39.58	39.65	39.81
	White Reflectance	0.608	0.389	0.560	0.475	0.423	0.412
	Contrast Ratio	**18.4**	**6.4**	**15.0**	**12.3**		**11.2**
45 degrees	Black Luminance	1.296	2.016	1.354	1.424		1.426
	BaSO4 Luminance	38.29	38.23	38.5	38.73		38.88
	Black Reflectance	0.034	0.053	0.035	0.037		0.037
	White Luminance	22.67	14.58	20.92	18.11	16.26	16.12
	BaSO4 Luminance	38.3	38.37	38.38	38.61	38.66	38.86
	White Reflectance	0.592	0.380	0.545	0.469	0.421	0.415
	Contrast Ratio	**17.5**	**7.2**	**15.5**	**12.8**		**11.3**
30 degrees	Black Luminance	1.205	1.46	1.261	1.303		1.248
	BaSO4 Luminance	36.7	36.66	36.88	37.1		37.13
	Black Reflectance	0.033	0.040	0.034	0.035		0.034
	White Luminance	21.21	14	21.13	17.95	**15.63**	15.86
	BaSO4 Luminance	36.68	36.76	36.73	37.02	37.08	37.33
	White Reflectance	0.578	0.381	0.575	0.485	0.422	0.425
	Contrast Ratio	**17.6**	**9.6**	**16.8**	**13.8**		**12.6**

As in the previous table, the raw data are in the unshaded cells and the first two shaded rows for a specific measurement angle are the black and white reflectance coefficients, respectively. The third shaded row for each measurement angle section is the calculated contrast ratio for that hose and for that particular viewing (measurement) angle. Again, hose sample #5 was a white hose with no black markings and therefore, no contrast was calculated for this sample.

3.2 Specular (mirror-like) Reflection - Effect of Equal Viewing and Illumination Angle

The objective of this set of measurements was to determine how much the reflectance coefficient of the various hoses change as a function of the viewing angle for a specular reflection geometry. This was only done for the visible light spectrum (nominally 400-700 nm) using the hand-held photometer. Data were collected for 3 different viewing and lighting angles. Figure 5 shows the basic equipment set-up for this measurement.

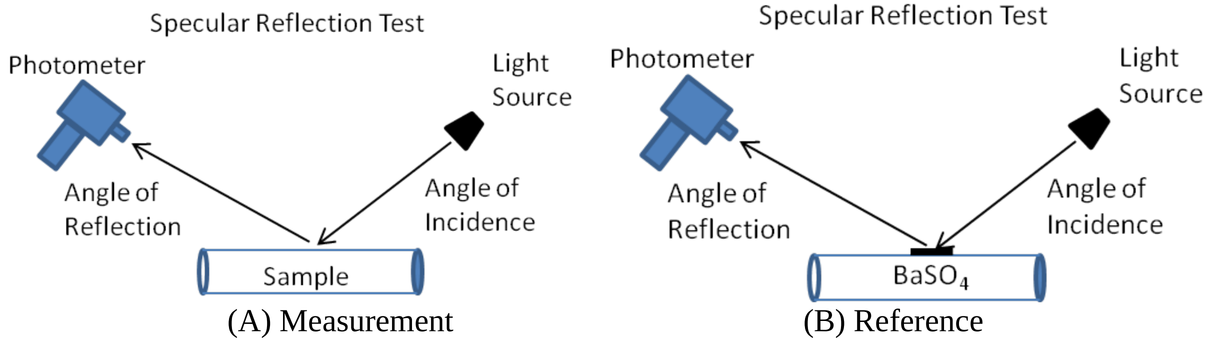

Figure 5. Basic geometry for measuring specular (mirror-like) reflectivity effects.

Figure 5 (A) depicts the measurement of the apparent luminance of the refueling hose (both the light and dark parts separately) due to the directional illuminance provided by the light source. The (B) figure depicts how the reference surface (BaSO4 plate) is measured at the same angles to determine what the perfect Lambertian reflector surface would produce in the way of luminance under the same illumination and angle conditions. The ratio of these two readings (the "A" reading and the "B" reading) is the reflection coefficient for the section of hose sample measured (the light or dark part) for the illumination and viewing angle used. Measurements were made for viewing/measurement angles of 30 degrees, 45 degrees, and 60 degrees.

Figure 6. Physical set-up to measure specular reflectivity.

The refueling hose sample was placed between the uprights shown at the left side of Figure 6. The light source and photometer are at the right side of the photograph. The optical rails mounted to the table top were set for viewing/reflection angles of 30, 45, and 60 degrees from parallel to the surface of the sample. That makes 60 degrees the "steepest" viewing angle with respect to the surface and the angle at which one would expect the least specular effects and 30 degrees should be the angle that we see the highest specular effects (if any are present). Figure 7 is a view from just behind the photometer with the photometer set up in the 60 degree viewing angle and aimed at the white part of the hose sample. The BaSO4 reference surface was placed between the two black uprights shown in the center of the picture when it was time to measure the reference luminance produced by the illumination source (which is "off-picture" to the right).

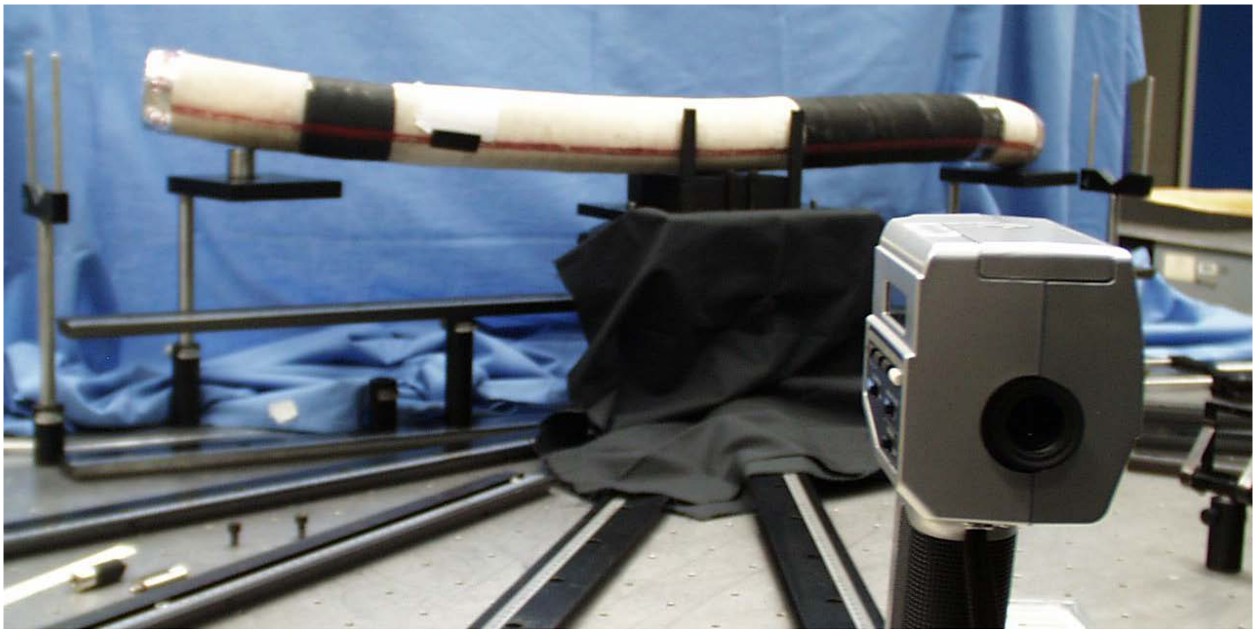

Figure 7. View from behind the photometer for white portion of hose measurement at 60 deg angle.

The measurement set-up in Figure 7 was accomplished for light and dark sections of all six hose samples and all three viewing/illumination angles. From these data, the reflection coefficients of the light and dark part of the six hose samples were calculated for the 3 viewing/illumination angles. Tables 6 and 7 are a summary of these results for the "uncleaned" and "cleaned" hose samples respectively.

Table 6. BEFORE CLEANING: Summary of specular reflection effects (extracted from AFRL-RH-WP-TR-2012-0145).

Angle from horizontal	Item	Sample Number - Before Cleaning					
		1	2	3	4	5	6
60 degrees	Black Luminance	3.8	6.92	6.24	8.68		4.88
	BaSO4 Luminance	103.9	103.3	106.1	103.9		104.5
	Black Reflectance	**0.037**	**0.067**	**0.059**	**0.084**		**0.047**
	White Luminance	71.88	34.42	41.33	50.85	47	31.9
	BaSO4 Luminance	103.2	103.1	105.1	104.2	103.1	102.1
	White Reflectance	**0.697**	**0.334**	**0.393**	**0.488**	**0.456**	**0.312**
	Contrast Ratio	**19.0**	**5.0**	**6.7**	**5.8**		**6.7**
45 degrees	Black Luminance	3.63	11.39	9.2	9.59		5.04
	BaSO4 Luminance	81.52	82.42	83.76	82.22		78
	Black Reflectance	**0.045**	**0.138**	**0.110**	**0.117**		**0.065**
	White Luminance	55.2	34.36	33.68	34.57	47	20.96
	BaSO4 Luminance	82.5	80.31	82.77	80.91	82.93	81.23
	White Reflectance	**0.669**	**0.428**	**0.407**	**0.427**	**0.567**	**0.258**
	Contrast Ratio	**15.0**	**3.1**	**3.7**	**3.7**		**4.0**
30 degrees	Black Luminance	4.92	22.47	16.46	15.14		8.07
	BaSO4 Luminance	59.08	62.25	60.91	60.81		60.44
	Black Reflectance	**0.083**	**0.361**	**0.270**	**0.249**		**0.134**
	White Luminance	39.52	43.33	35.18	28.12	68.7	13.44
	BaSO4 Luminance	60.52	60.51	60.92	55.87	61	58.16
	White Reflectance	**0.653**	**0.716**	**0.577**	**0.503**	**1.126**	**0.231**
	Contrast Ratio	**7.8**	**2.0**	**2.1**	**2.0**		**1.7**

The white data cells in Table 6 are the raw luminance measurements using the previously described geometry and technique. The lightly shaded cells are the reflectance coefficients calculated from the raw data and the more heavily shaded cells are the resultant contrast ratio values ("white" hose section divided by "black" hose section values) calculated for each hose and viewing angle. These data are for the hose samples *before* cleaning.

Table 7. AFTER CLEANING: Summary of specular reflection effects.

Angle from horizontal		Sample Number - CLEANED 1	2	3	4	5	6
60 degrees	Black Luminance	1.012	4.258	1.451	1.325		1.1
	BaSO4 Luminance	32.6	33	32.9	32.94		32.64
	Black Reflectance	**0.031**	**0.129**	**0.044**	**0.040**		**0.034**
	White Luminance	17.53	16.01	19.78	16.19	18.45	14.01
	BaSO4 Luminance	32.74	33.48	32.97	32.93	32.65	32.87
	White Reflectance	**0.535**	**0.478**	**0.600**	**0.492**	**0.565**	**0.426**
	Contrast Ratio	**17.2**	**3.7**	**13.6**	**12.2**		**12.6**
45 degrees	Black Luminance	1.11	6.548	1.316	1.207		1.047
	BaSO4 Luminance	27.17	26.87	27.49	27.47		27.54
	Black Reflectance	**0.041**	**0.244**	**0.048**	**0.044**		**0.038**
	White Luminance	13.79	16.75	17.4	13.55	19.21	10.69
	BaSO4 Luminance	27.48	27.73	27.67	27.54	27.1	27.54
	White Reflectance	**0.502**	**0.604**	**0.629**	**0.492**	**0.709**	**0.388**
	Contrast Ratio	**12.3**	**2.5**	**13.1**	**11.2**		**10.2**
30 degrees	Black Luminance	1.492	16.78	1.746	1.714		1.149
	BaSO4 Luminance	21.16	22.03	21.64	21.55		22.1
	Black Reflectance	**0.071**	**0.762**	**0.081**	**0.080**		**0.052**
	White Luminance	10.47	29.96	18.46	13.59	**27.52**	11.23
	BaSO4 Luminance	21.15	21.99	21.45	21.45	21.24	21.25
	White Reflectance	**0.495**	**1.362**	**0.861**	**0.634**	**1.296**	**0.528**
	Contrast Ratio	**7.0**	**1.8**	**10.7**	**8.0**		**10.2**

The white data cells in Table 6 are the raw luminance measurements using the previously described geometry and technique. The lightly shaded cells are the reflectance coefficients calculated from the raw data and the more heavily shaded cells are the resultant contrast ratio values ("white" hose section divided by "black" hose section values) calculated for each hose and viewing angle. These data are for the hose samples *after* cleaning.

4 ANALYSIS AND DISCUSSION

4.1 Effect of Hose Sample Cleaning on Non-specular Reflection Viewing Geometry Contrast (photometer perpendicular to hose surface)

The data contained in Tables 2 and 3 under the Results section are analyzed in this section. Table 8 is a summary of the average contrast ratio calculated for each sample hose section (except for hose #5, which was an "all white" hose) before and after cleaning. Figure 8 is a graphical representation of the contrast ratios of Table 8. In general, the results are more or less what one might expect in that after cleaning the hose samples exhibited higher (better) contrast ratios. This measurement geometry is probably the closest to the conditions under which the photographs in Figure 1 were taken and generally support the subjective impression one gets from viewing Figure 1. However, subjective impressions can be deceiving.

Table 8. Effect of cleaning on contrast ratio for non-specular reflection measurement procedure shown in Figure 2.

	Contrast Ratio	
	Uncleaned	Cleaned
hose 1	19.6	20.1
hose 2	6.8	9.9
hose 3	15.3	15.4
hose 4	13.7	15.3
hose 6	8.3	12.3

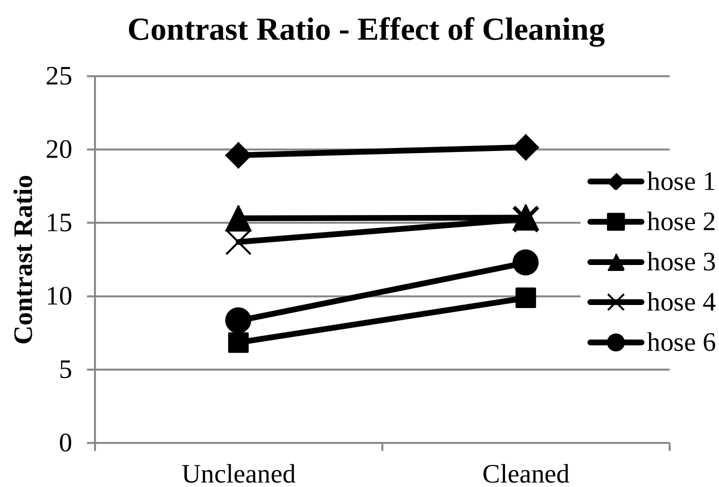

Figure 8. Graphic portrayal of Table 8 contrast ratios.

Table 9. Effect of cleaning on reflectance coefficients.

	White Reflectance		Black Reflectance	
	Uncleaned	Cleaned	Uncleaned	Cleaned
hose 1	0.678	0.612	0.035	0.030
hose 2	0.279	0.393	0.041	0.040
hose 3	0.619	0.541	0.040	0.035
hose 4	0.674	0.512	0.052	0.034
hose 5	0.358	0.401		
hose 6	0.292	0.446	0.035	0.036

Table 9 is a summary of the black and white reflectance coefficients that were used to calculate the contrast ratios of Table 8 and Figure 8. One would expect that cleaning the hoses would result in "blacker blacks" and "whiter whites" or, at a minimum, the reflectance coefficients should stay the same if there were no dirt or scuff marks to remove. However, Table 9 and

Figure 9 show that although all hose samples have lower black reflectance coefficients (for this measurement geometry) after cleaning, it is *not* the case that all white reflectance coefficients improved (higher value) after cleaning. Hoses 1, 3, and 4 show lower white reflectance coefficients after cleaning.

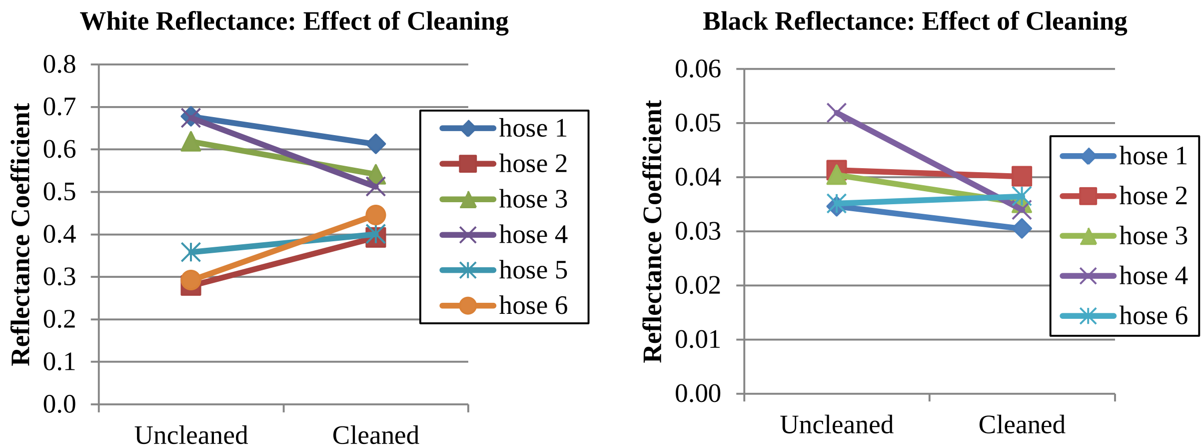

Figure 9. Graphic representation of the black and white reflectance coefficients of Table 9.

Figure 10. Hose samples that showed lower white reflectance coefficients after cleaning: upper picture of each pair is *after* cleaning and the lower picture is *before* cleaning.

Looking at Figure 10, hose 4, it is apparent why the black reflectance was lower after cleaning as the white scuff marks in the lower picture were removed by cleaning as indicated by the upper picture. However, it is not readily apparent that the white part of all three hoses of Figure 9 became less white; although the measurements clearly show this is the case. The lighting conditions under which the before and after cleaning pictures were taken were most likely somewhat different and could account for the difference in the apparent "whiteness" of the white sections (before and after cleaning) compared to the measured values.

Hose 1 was described as new, so one would not expect it to improve in contrast (or reflectance coefficients) due to cleaning. However, one would certainly not expect a reduced white reflectance due to cleaning. Some of the cleaning effects are certainly due to dirt/scuff marks that were removed during cleaning but some effects might have to do with the effects of the cleaning process on the optical characteristics of the hose surface itself. It must be noted that the white section of the new hose had a lower reflectance after cleaning, possibly due to experimental variation.

4.2 Effect of Hose Sample Cleaning on Non-specular Reflection Viewing Geometry Contrast (illumination source perpendicular to hose surface)

Analysis conducted in this section is based on data contained in Tables 4 and 5, which were collected under the non-specular reflection geometry shown in Figure 3. Table 10 is a summary of the effects of cleaning on the contrast ratio of the hose samples.

Table 10. Summary of the effects of cleaning on contrast ratio for the non-specular viewing geometries shown in Figure 3.

	Contrast Ratio					
	60 deg		45 deg		30 deg	
	Uncleaned	**Cleaned**	**Uncleaned**	**Cleaned**	**Uncleaned**	**Cleaned**
Hose 1	17.7	18.4	17.8	17.5	17.8	17.6
Hose 2	5.5	6.4	7.1	7.2	6.8	9.6
Hose 3	16.0	15.0	16.2	15.5	16.0	16.8
Hose 4	9.4	12.3	9.7	12.8	9.8	13.8
Hose 6	7.9	11.2	7.2	11.3	6.5	12.6

Although there were some differences associated with the angle of view/measurement, in general, the results of the non-specular contrast ratios were similar to what was found in Section 4.1. Once again, hoses 1, 3 and 4 exhibited a reduction in the measured reflectance coefficients for the white parts of the hoses after cleaning (see Tables 11 and 12).

Table 11. Cleaning effects on reflectance coefficients for the 60 degree viewing/measurement angle.

60 Deg	**White Reflectance Coeff**		**Black Reflectance Coeff**	
	Uncleaned	**Cleaned**	**Uncleaned**	**Cleaned**
Hose 1	0.657	0.608	0.037	0.033
Hose 2	0.301	0.389	0.055	0.061
Hose 3	0.664	0.560	0.042	0.037
Hose 4	0.625	0.475	0.067	0.038
Hose 5	0.364	0.423		
Hose 6	0.284	0.412	0.036	0.037

Table 12. Cleaning effects on reflectance coefficients for the 30 degree viewing/measurement angle.

30 Deg	**White Reflectance Coeff**		**Black Reflectance Coeff**	
	Uncleaned	**Cleaned**	**Uncleaned**	**Cleaned**
Hose 1	0.629	0.578	0.035	0.033
Hose 2	0.273	0.381	0.040	0.040
Hose 3	0.654	0.575	0.041	0.034
Hose 4	0.624	0.485	0.064	0.035
Hose 5	0.352	0.422		
Hose 6	0.246	0.425	0.038	0.034

4.3 Effect of Hose Sample Cleaning on Specular Reflection Viewing/measurement Geometry Contrast Ratios (illumination and photometer viewing angles equal and opposite with respect to hose surface)

Analysis for this section is based on data from Tables 6 and 7 and the specular viewing/measurement geometry described in Figure 5. This section is perhaps the most important in that it provides results (especially for the 30 deg angle) based on measurements that use viewing/measurement geometries that are the most similar to the pilot's view of the hose during refueling operations.

Table 13 is a summary of the contrast ratios calculated for the different viewing angles before and after cleaning. Since hose number 5 was an all-white hose no contrast ratio exists for it and it is therefore missing from Table 13.

Table 13. Summary of contrast ratios before and after cleaning.

	60 deg		45 deg		30 deg	
	Uncleaned	**Cleaned**	**Uncleaned**	**Cleaned**	**Uncleaned**	**Cleaned**
Hose 1	19.0	17.2	15.0	12.3	7.8	7.0
Hose 2	5.0	3.7	3.1	2.5	2.0	1.8
Hose 3	6.7	13.6	3.7	13.1	2.1	10.7
Hose 4	5.8	12.2	3.7	11.2	2.0	8.0
Hose 6	6.7	12.6	4.0	10.2	1.7	10.2

The results of this section may require further investigation. One might expect, as in the other contrast ratio measurement geometries, that cleaning should improve the contrast ratio. Looking at Table 13, one sees that contrast ratio got worse for all viewing angles (for these specular reflection viewing geometries) for two of the hoses (1 and 2) after cleaning. The other three hoses benefited from the cleaning process demonstrating a significant improvement in contrast ratio. What is unexpected is that for the 30 degree viewing angle (the one that comes closest to the pilot's view of the hose during refueling) the contrast ratios of the three used hoses showed a higher contrast ratio than the new hose after they were cleaned (see Figure 13). For viewing/measurement angles closer to perpendicular to the surface of the hose (Figures 12 and 13), the new hose (hose #1) has a better or about equal contrast ratio to three of the cleaned, used hoses. Note that the lowest contrast ratio that one can get is 1.0, which corresponds to no contrast.

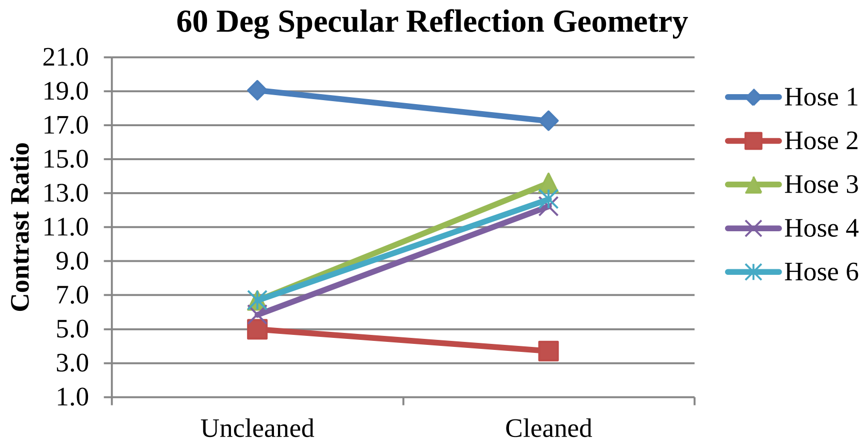

Figure 11. Contrast ratios of the hoses for a 60 degree viewing/measurement angle, specular reflection geometry before and after cleaning.

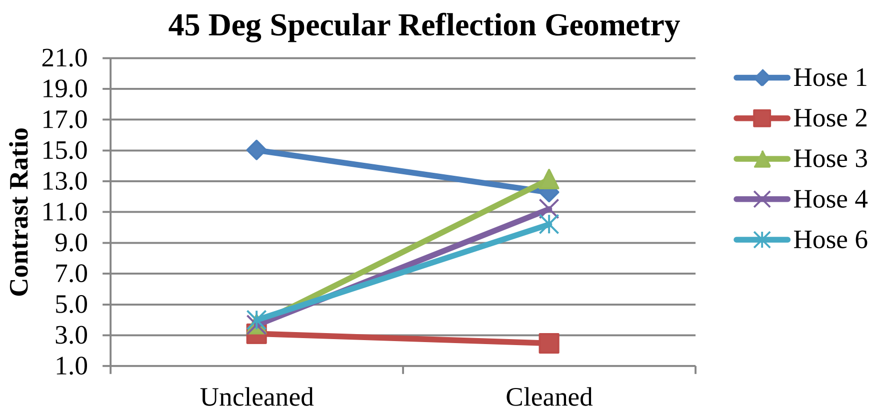

Figure 12. contrast ratios of the hoses for a 45 degree viewing/measurement angle, specular reflection geometry before and after cleaning.

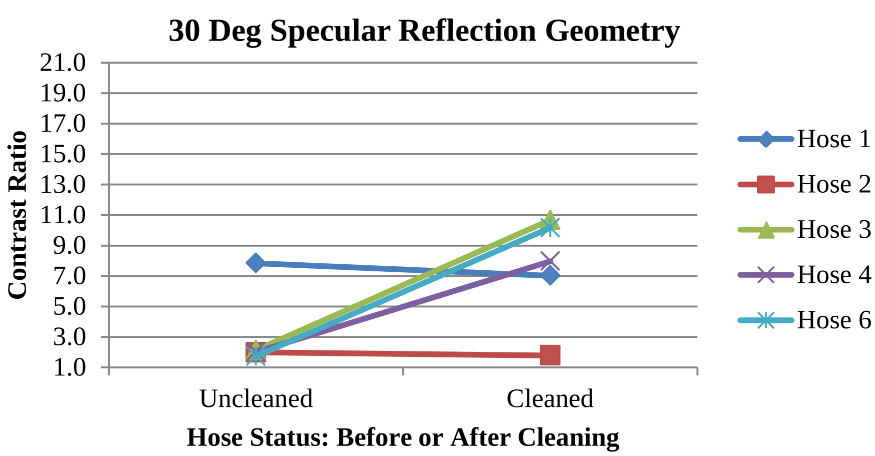

Figure 13. Contrast ratios of the hoses for a 30 degree viewing/measurement angle, specular reflection geometry before and after cleaning.

Contrast ratio does not tell the whole story when it comes to what effects cleaning had on the specular reflection effects of the hose samples. In order to try to figure out what is going on, one must look at the actual reflection coefficients for the black and white parts of the hose before and after cleaning. Table 14 is a summary of the black and white reflection coefficients before and after cleaning for the 60 degree specular reflection viewing/measurement geometry. Figure14 shows these same data in graphical form for easier interpretation.

Table 14. Summary of white and black reflection coefficients before and after cleaning for the 60 degree specular reflection viewing/measurement geometry.

60 Deg	White Reflectance Coeff		Black Reflectance Coeff	
	Uncleaned	Cleaned	Uncleaned	Cleaned
Hose 1	0.697	0.535	0.037	0.031
Hose 2	0.334	0.478	0.067	0.129
Hose 3	0.393	0.600	0.059	0.044
Hose 4	0.488	0.492	0.084	0.040
Hose 6	0.312	0.426	0.047	0.034

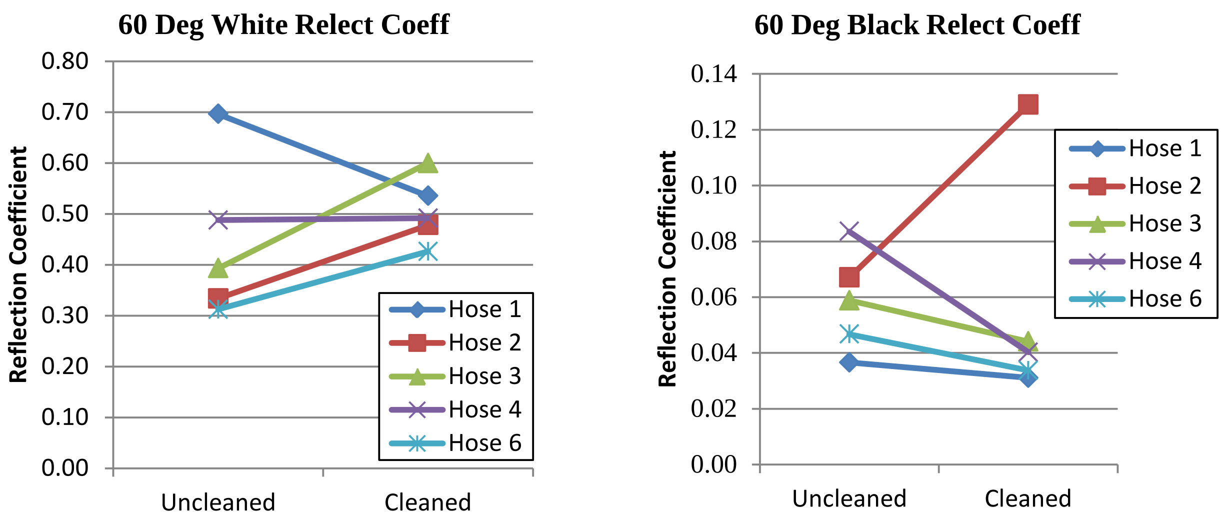

Figure 14. Graphical representation of white and black reflection coefficients before and after cleaning for the 60 degree specular reflection view/measurement geometry.

Looking at Figure 14, it is apparent that cleaning increased the "whiteness" of the white part of the hose for hoses 2, 3 and 6 but for hose 4 there was almost no effect on the white reflection coefficient and, just like in sections 4.1 and 4.2, the new hose (number 1) shows a reduction in the white reflection coefficient after cleaning. The black reflection coefficient was decreased (improved) for all hoses except hose number 2, which shows a substantial increase in reflectivity after cleaning. The results are somewhat similar for the 30 degree viewing/measurement angle as shown in Table 15 and Figure 15. One aspect of these data is that the white reflection coefficient for the "new" hose (hose 1) is worse after cleaning than any of the other four hoses. This would suggest the new hose, even after cleaning, is less "shiny" than the used hoses. Why should a new hose, after cleaning, be less specularly reflective than used hoses after cleaning? In addition, from section 4.1 and 4.2 results the new hose reflects less light in non-specular reflection geometries after the cleaning process. This suggests there is some aspect of the materials used in hose 1 that do not react as well to the cleaning process compared to the materials of the other hoses - although the issue may be a more complex one that involves the aging of the materials as well. This suggests it is important to determine how well the cleaning process is suited for the particular hose materials selected for the exterior of the hose.

Table 15. Summary of white and black reflection coefficients before and after cleaning for the 30 degree specular reflection viewing/measurement geometry.

30 Deg	White Reflectance Coeff		Black Reflectance Coeff	
	Uncleaned	Cleaned	Uncleaned	Cleaned
Hose 1	0.653	0.495	0.083	0.071
Hose 2	0.716	1.362	0.361	0.762
Hose 3	0.577	0.861	0.270	0.081
Hose 4	0.503	0.634	0.249	0.080
Hose 6	0.231	0.528	0.134	0.052

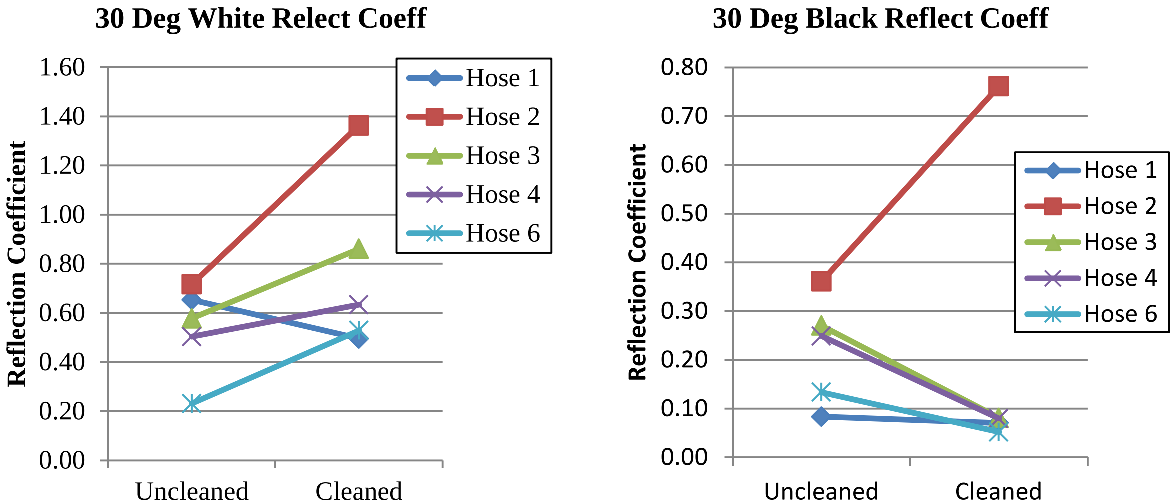

Figure 15. Graphical representation of white and black reflection coefficients before and after cleaning for the 30 degree specular reflection view/measurement geometry.

5 CONCLUSIONS/RECOMMENDATIONS

As was noted in the original report on this topic (AFRL-RH-WP-TR-2012-0145), it is apparent that the contrast between the black and white sections of the refueling hoses measured is highly dependent on the viewing and illumination angle geometry. Any evaluation of a possible new hose material needs to take this fact into account so that the evaluation conditions will provide results comparable to operational results.

The primary objective of this effort was to investigate the effects of cleaning on the contrast ratio (visibility) of the hose samples. One would expect that cleaning would, in general, improve the contrast between the black and white sections of the hose. While this was, indeed, generally true for used hose samples 3, 4, and 6 it was definitely not true for new hose sample 1. The cleaning process used decreased the reflectance coefficient of the white section of hose 1 for all specular and non-specular viewing/measurement geometries, implying the cleaning process did not interact well with the materials of this hose. This hose may have been made of different materials than the other hoses. The fact that the white reflection coefficient for this *new* hose, after cleaning, was even lower than the other *used* hoses after cleaning (for the 30 degree specular viewing/measurement geometry) is worthy of future investigation. At a minimum, any prospective new hose should undergo a standard cleaning procedure to verify that the cleaning procedure does not degrade the optical characteristics of the hose material. Likewise, cleaning procedures should be investigated to determine if they are, indeed, benign with respect to the hose materials.

6 REFERENCES

Bartell, R. J., Unger, S. E., & Task, H. L. (1993). *Backscatter haze device for measurement of haze in aircraft transparencies* (Report No. AL/CF-TR-1993-0102). Wright-Patterson AFB, OH: Armstrong Laboratory.

Ellis, S.A., Pinkus, A. R., Task, H.L. (2012). *Assessment of Refueling Hose Visibility* (Report No. AFRL-RH-WP-TR-2012-0145). Wright-Patterson, AFB, OH: Air Force Research Laboratory.

van Cott, H.P., and Kinkade, R.G. (Eds.), *Human Engineering Guide to Equipment Design*. Washington, DC: GPO.

F-35 Gen 5 HMDS spec for minimum symbology contrast against a 10,000 fl background.

Farrell, R .J. & J. M. Booth, "Design Handbook for Imagery Interpretation Equipment", *Boeing Aerospace Company Report*, D180-19063-1, Boeing Aerospace Company, Seattle, WA, 1984.

Joint Helmet Mounted Cuing System (JHMCS) specification for minimum display contrast against 10,000 fl background.

MIL-STD-150A, MILITARY STANDARD: PHOTOGRAPHIC LENSES (12 MAY 1959)

Pinkus, A. R., Task, H. L., Barbato, M. H., Hausmann, M. A. & Dixon, S. A. (2003). Aerospace Transparency Research Compendium. (Report No. AFRL-HE-WP-TR-2003-0084). Wright-Patterson AFB, OH: Air Force Research Laboratory.

RCA Electro-Optics Handbook (1974). Technical Series EOH-11. RCA Solid State Division, Electro Optics and Devices, Lancaster PA, pp. 70, 75.

Runnels, Lance Cpl. Kyle N, ROTOVUE on-line publication, 23 May 2012. *VMM-162 refuels under cover of darkness*, URL: http://www.camplejeuneglobe.com/rotovue/news/around_the_corps/article_3be9f1a6-a415-11e1-84be-001a4bcf887a.html.

7. APPENDICES

APPENDIX A: Aerial Refueling Hose Color and Markings Evaluation Criteria
Dex Kalt
14 Sept 2011

1. Requirement
Determine optimum aerial refueling hose markings and color on probe drogue automatic hose take-up type aerial refueling systems for use as a formation aid for receiver pilots. The hose markings should assist pilots in detecting hose movement and position while hooked up.

2. Supporting information
During the aerial refueling operation, the aerial refueling drogue, a hose stabilizing device, is the closest object in the receiver pilot's field of vision (prior to and after hook-up). This devise is approximately (with high-speed and fixed wing aircraft) two feet in diameter typically equipped with a 4" wide white cloth canopy which is attached to the outer struts. In many applications, white wide angle reflective tape is sewn into the canopy to enhance its visibility to pilots. In addition, several applications have drogue lights illuminating the drogue interior and/or LEDs to illuminate the exterior of the drogue attaching coupling.

A similar drogue which incorporates a white canopy over 52" in diameter with a 1 foot wide white cloth used for rotary wing helicopters aerial refueling. Night aided vision typically is used by the US services for night aerial refueling for rotary winged aircraft.

3. Criteria
The following criteria should be considered in determining and evaluating the subject requirements.

3.1 Acceptable minimum / maximum hose color to marking contrast range under a variety of lighting conditions. This should permit the pilots to detect hose movement and position from the tanker hose / drogue exit. This distance (pilot eye to drogue exit) may range from approximately 10 ‘ to 90 ‘ depending on the type of tanker drogue hose reel retracting / storage system.

3.2 Minimum / maximum hose marking bands' widths.

3.3 Hose drogue stowage exit light illuminating required for the associated factors of 3.1 and 3.2 above.

3.4 Access relationship of other primary receiver pilot tanker aircraft formation and position aids used in addition to the aircraft hose exit area.

3.5 Determine the need and hose markings spacing and size for receiver pilot to detect hose movement and rate of movement in relationship to the tanker i.e. 10 ‘ marking on current aircraft hoses.

3.6 Determine the need and spacing / size of hose position markings.

3.6.1 inner hose limit

3.6.2 outer hose limit

3.6.3 middle / sweet spot markings for holding tanker position (will vary with type aircraft and installation)

3.7 Need for in-service cleaning and maintenance and frequency for inspecting and insuring contrasting color markings range (as established in item 3.1 above) is maintained for pilot visibility throughout the hose life.

3.8 Investigate whether hose life is impacted by basic hose color, black/white or other.

3.9 Whether hose construction material selection for markings and endurance of these markings under repeated use in service applications, hose reel wrap, abrasion, etc. and cleanliness, maintenance etc.

4.0 Reference past test documents / reports of aerial refueling hoses.

APPENDIX B: Proposed Assessment of Refueling Hose Visibility

H.L. Task
30 Nov 2011

This proposal is based on a 22 Nov 2011 telecon that included ARSAG, Navair, and AFRL personnel and is in response to a request from ARSAG. The primary goal of these evaluations is to assess the visibility of the hose samples.

Samples: ARSAG will supply 3 or more hose samples (3-4 feet long) - white on black, black on white, and "dirty" white hose. Each sample will be clearly marked (new, old, dirty, etc.).

Measurements:

1) Spectral reflectivity: Two spectral reflectivity measurements will be done on each hose and each color segment (3 hoses times 2 colors each times 2 replications = 12 spectral reflectivity measurements. The replications will be on the same color/hose but in a different location. If the two measurements differ by too much (e.g., 5% of value) a third measurement will be made. Spectral range will include visible through NIR and SWIR, if possible (nominally 400nm - 2000nm). These measurements will be done perpendicular to the surface with broad spectrum illumination on the samples in a non-specular reflection geometry. A $BaSO_4$ Lambertian reflectance reference will be positioned next to each measurement location and will be measured as a reference. The spectral reflectivity for each location measured is the ratio of the sample measurement and the reference measurement.

2) Photometric reflectance: Although photometric reflectance (visible light) can and will be calculated from the spectral measurements above, this measurement will allow for a direct measurement of the photometric reflectance and serve as a cross-check. The same procedure as outlined above will be used except that the measurements will be made by a photometer. The photometric reflectance is the ratio of the luminance of the sample and the luminance of the $BaSO_4$ reference.

3) Specular (mirror-like) effects: It is assumed that both the white and black parts of the hoses are essentially flat; which means they reflect light uniformly in all directions independent of the directionality of the light source or the observer. The purpose of this measurement is to check that assumption. A photometer will be used to measure the luminance of the sample and the luminance of an adjacent $BaSO_4$ reference. However, the illumination in this case will be a light source positioned in a reflection geometry and two measurements will be made for each hose location measured. The light source (e.g., photo flood light) will be positioned to illuminate the hose at approximately a 30 degree angle from horizontal. The luminance of the hose and the reference will be made with the photometer perpendicular to the hose/reference and then at a 30 degree angle with respect to horizontal on the opposite side from the light source. The reflectance of the hose will be calculated for each of the viewing geometries to determine if there is a significant difference between them.

4) Photographic documentation: In order to provide documentation of the measurements and for a visual cross-check the samples will be photographed using three different spectral band sensors: visible, near IR, and short-wave IR. These images will be captured for each of the samples set up for both the geometries described in 2) and 3) above. Other photographs may be produced as appropriate.

Analysis:

1) The spectral reflectivity measurements of 1) above will be used to calculate the reflectivity of each point measured for each of the 3 spectral bands of interest: visible, NIR, SWIR.

2) The visible spectral reflectivity values obtained above will be compared to the photometric (visible light) reflectivity measured in 2) above.

3) A theoretical discussion of hose visibility will be provided with the calculated contrast of the black and white hose markings and possible backgrounds. Also, the theoretical (and real) effects of contrast loss due to aircraft windscreens and HUD combiners will be addressed and analyzed in the context of the hose reflectivity measurements.

Deliverables: A final report on the results obtained in this evaluation will be provided along with whatever recommendations are appropriate, based on the results.

APPENDIX C: Test Plan: Assessment of Refueling Hose Visibility

H.L. Task
3 April 2012 - updated 6-23-2012

Samples: ARSAG will supply five - six hose samples (3-4 feet long) - white on black, black on white, and "dirty" white hose. Each sample will be clearly marked with a tag attached to one end of the sample hose section. The tag will include the type of hose and its basic characteristics (new, old, dirty, white on black, black on white, etc.). Additionally, samples will be clearly labeled with a number (1 through N where N is 6 or less) and a photograph will be taken of each numbered hose section sample with a clearly readable placard that includes the sample number in large numbers.

1) Spectral reflectivity

Measurement: Two spectral reflectivity measurements will be done on each hose and each color segment (e.g., 3 hoses times 2 colors each times 2 replications = 12 spectral reflectivity measurements). The replications will be on the same color/hose, but in a different location. If the two measurements differ by too much (e.g. 5% of value), a third measurement will be made. Spectral range will include visible (nominally 400nm to 700nm) through NIR (680nm to 950nm) and SWIR (950nm to 1300nm, and, to the extent possible, LWIR). These measurements will be done perpendicular to the surface with broad spectrum (incandescent) illumination on the samples in a non-specular reflection geometry. A $BaSO_4$ Lambertian reflectance reference will be positioned at each measurement location and will be measured as a reference. The spectral reflectivity for each location measured is the ratio of the sample measurement and the reference measurement as a function of wavelength. The pictures below show the geometry for making the spectral radiometric scans.

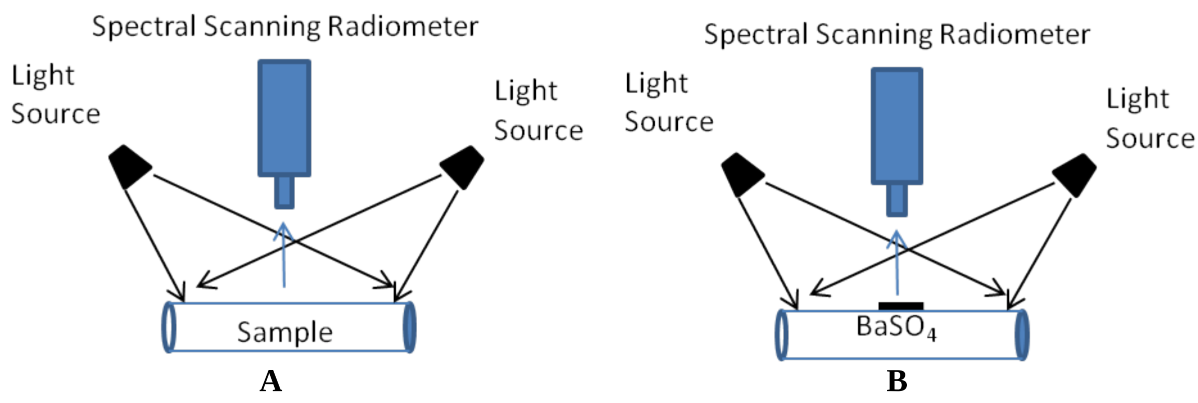

Figure 16. Spectral scanning radiometer geometry - A is the scan geometry for scanning the hose sample and B is the geometry for scanning the reference.

The light sources shown in Figure 16A are incandescent and provide a broad spectrum of illumination. The light sources will be several feet away from the sample and should provide the vast majority of the light that is illuminating the sample (room lights MAY need to be turned off). Without changing anything, after the sample has been scanned, the $BaSO_4$ reference will be placed on top of the area of hose sample that was measured and a reference scan will be made. The area of the sample hose that will be measured will be relatively small - on the order of 1-2 centimeters in diameter. The table below summarizes the various spectral curves that will be measured/calculated. If Data-Takes A and B are more than 5% different in values, then Data-Take C will be accomplished. Each Data-Take is at a different location on the hose.

Table 16. Spectral scans accomplished with the spectral scanning radiometer.
Note: the contents of each cell correspond to the Sample number (1-6), the scan type (Sample or BaSO4), the "color" (Black or White), and the data-take session (A, B, or C). Each cell also corresponds to a spectral curve that graphs spectral radiance as a function of wavelength.

			Sample number (1 – 6)				
		Spectral curves	**1**	**2**	**3**	**4**	**5**
Data take A	Black (B)	A. Sample scan	1SB-A	2SB-A	3SB-A	4SB-A	5SB-A
		B. $BaSO_4$ scan	1BB-A	2BB-A	3BB-A	4BB-A	5BB-A
		Calculate ratio A/B	1RatioB-A	2RatioB-A	3RatioB-A	4RatioB-A	5RatioB-A
	White (W)	A. Sample scan	1SW-A	2SW-A	3SW-A	4SW-A	5SW-A
		B. $BaSO_4$ scan	1BW-A	2BW-A	3BW-A	4BW-A	5BW-A
		Calculate ratio A/B	1RatioW-A	2RatioW-A	3RatioW-A	4RatioW-A	5RatioW-A
Data take B	Black (B)	A. Sample scan	1SB-B	2SB-B	3SB-B	4SB-B	5SB-B
		B. $BaSO_4$ scan	1BB-B	2BB-B	3BB-B	4BB-B	5BB-B
		Calculate ratio A/B	1RatioB-B	2RatioB-B	3RatioB-B	4RatioB-B	5RatioB-B
	White (W)	A. Sample scan	1SW-B	2SW-B	3SW-B	4SW-B	5SW-B
		B. $BaSO_4$ scan	1BW-B	2BW-B	3BW-B	4BW-B	5BW-B
		Calculate ratio A/B	1RatioW-B	2RatioW-B	3RatioW-B	4RatioW-B	5RatioW-B
Data take C (optional)	Black (B)	A. Sample scan	1SB-C	2SB-C	3SB-C	4SB-C	5SB-C
		B. $BaSO_4$ scan	1BB-C	2BB-C	3BB-C	4BB-C	5BB-C
		Calculate ratio A/B	1RatioB-C	2RatioB-C	3RatioB-C	4RatioB-C	5RatioB-C
	White (W)	A. Sample scan	1SW-C	2SW-C	3SW-C	4SW-C	5SW-C
		B. $BaSO_4$ scan	1BW-C	2BW-C	3BW-C	4BW-C	5BW-C
		Calculate ratio A/B	1RatioW-C	2RatioW-C	3RatioW-C	4RatioW-C	5RatioW-C

Analysis/Results: The data collected in Table 16 will be used to calculate the contrast ratios for each hose sample, spectral range and Data-Take as outlined in the table below:

Table 17. Contrast ratios for the different spectral ranges and hose samples.
Note: each Contrast Ratio cell will contain a number greater than one since the contrast ratio is defined as the higher radiance divided by the lower radiance. The other cells will contain a number less than one, which is the fraction of light that is reflected from the sample.

			Sample number				
Spectral Range			**1**	**2**	**3**	**4**	**5**
Data Take A	Visible	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
	Near IR	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
	Short Wave IR	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
Data Take B	Visible	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
	Near IR	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
	Short Wave IR	Black Reflectance					
		White Reflectance					
		Contrast Ratio					

2) Photometric reflectance

Measurement: Although photometric reflectance (visible light) can and will be calculated from the spectral measurements above, this measurement will allow for a direct measurement of the photometric (visible) reflectance and serve as a cross-check. The same procedure as outlined above will be used except that the measurements will be made by a photometer. The photometric reflectance is the ratio of the luminance of the sample and the luminance of the $BaSO_4$ reference.

Table 18. Photometric measurements of hose reflectance and contrast ratios.

		Sample Number 1	2	3	4	5
Data Take A	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					
Data Take B	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					
Data Take C	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					

Analysis/Results: The above table contains both the raw data values and the calculated reflectance and contrast ratio values. These can be compared with the values obtained using the spectral scanning radiometer.

NOTE: Procedurally, it will probably be most efficient and accurate if the spectral scanning radiometric measurements and the hand-held photometer measurements are done at essentially the same time. The procedure would be to set up the light sources, hose sample, and radiometer as depicted in Figure 17A. After making the spectral scan of the sample, a hand-held photometer would be held near the spectral scanning radiometer (without disturbing the hose sample, radiometer, or light sources) and a photometric reading would be obtained. After the photometric reading is obtained, the BaSO4 reference is placed on the sample over the area of the hose that was measured and another radiometric and photometric measurement of the BaSO4 reference would be made. Most likely, it will be easier to move the hose to the next location to be measured. The black areas and the white areas could be measured in any order, but the SPECIFIC area measured needs to be marked in some way to make sure one could get back to the same area - perhaps by using masking tape to OUTLINE the areas measured. As indicated above, 2 or 3 white areas and 2-3 black areas will be measured on each hose sample.

3) Specular (mirror-like) effects: It is assumed that both the white and black parts of the hoses are essentially flat (matte finish); which means they reflect light uniformly in all directions independent of the directionality of the light source or the observer. The purpose of this measurement is to check that assumption. A photometer will be used to measure the luminance of the sample and the luminance of a $BaSO_4$ reference. However, the illumination in this case will be a light source positioned in a reflection geometry (see Figure 17, A and B). Two measurements will be made for each hose location measured: one of the hose and one of the BaSO4 reference. The light source (e.g., photo flood light) will be positioned to illuminate the hose at various angles from horizontal (60, 45, 30 and, if possible, 15 degrees). The reflectance of the hose will be calculated for each of the viewing geometries to determine if there is a significant difference between them. Since this is a specular reflectance test, only two parts of each hose sample needs to be measured: a black area and a white area.

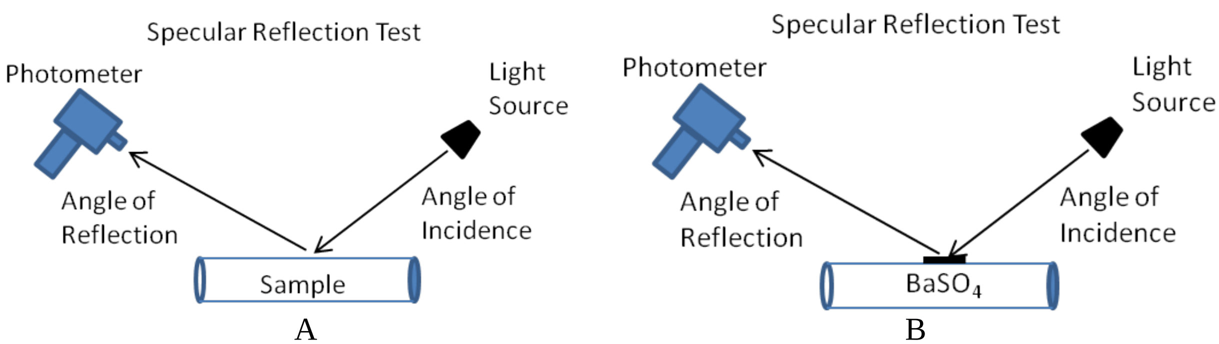

Figure 17. Equipment set-up to measure specular reflectance.

NOTE: Procedurally, it may be advantageous to use a laser pointer and an optical protractor to set the angle of incidence and the angle of reflection. The optical protractor would be placed at the part of the hose sample to be measured and the laser pointer would be adjusted such that the angle it arrives at the sample is one of the angles to be measured. The illuminating source, which should be located fairly far away from the sample so as to provide approximately parallel light illuminating the sample, would then be place in the location of the laser pointer. The same method could be used to establish the position of the small photometer, which could be tripod-mounted. Also, note that angles are measured from horizontal, not vertical. Previous measurements (1 and 2 above) were made at a 90 degree angle from horizontal.

Table 19. Measurement of reflectance and contrast ratios for specular lighting conditions.

Angle		Sample Number 1	2	3	4	5
60 degrees	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					
45 degrees	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					
30 degrees	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					

4) Photographic documentation: In order to provide documentation of the measurements and for a visual cross-check the samples will be photographed using three different spectral band sensors: visible, near IR, and short-wave IR. These images will be captured for each of the samples set up for both the geometries described in 2) and 3) above. Other photographs may be produced as appropriate including photographs to fully document the procedures and geometry suitable for the final report.

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AFRL – Air Force Research Laboratory
ARSAG – Aerial Refueling Systems Advisory Group
$BaSO_4$ – Barium Sulfate
BRDF – Bidirectional (azimuth and elevation) Reflectance Distribution Function
HUD – Head-Up Display
JHMCS – Joint Helmet Mounted Cuing System
LED – Light-Emitting Diode
LWIR – Long-Wave Infra-Red
Navair – U.S. Navy Naval Air Systems Command
NVG – Night Vision Goggles
SWIR – Short-Wave Infra-Red